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SCALE-EFFECT TESTS IN A TURBULENT TUNNEL OF THE NACA 65_3-418, a = 1.0 AIRFOIL SECTION WITH 0.20-AIRFOIL-CHORD SPLIT FLAP

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SCALE-EFFECT TESTS IN A TURBULENT TUNNEL OF THE NACA 65_3-418, a = 1.0 AIRFOIL SECTION WITH 0.20-AIRFOIL-CHORD SPLIT FLAP

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SUMMARY

The effect of Reynolds number on the aerodynamic characteristics of a low-drag airfoil section tested under conditions of relatively high stream turbulence was determined by tests in the LMAL 7- by 10-foot tunnel of the NACA 65_3-418, a = 1.0 airfoil section with a split flap having a chord 20 percent of the airfoil chord. The Reynolds number ranged from 0.19 to 2.99×10^6; the Mach number attained was never greater than 0.10. The data are presented as curves of section angle of attack, section profile-drag coefficient, and section pitching-moment coefficient against section lift coefficient for various flap deflections.

The maximum lift coefficient increased with Reynolds number. Deflecting the flap added an increment of maximum lift coefficient that seemed to be almost constant at all Reynolds numbers. The slope of the section lift curve with flap deflected showed no consistent variation with Reynolds number, although the slope of the section lift curve for the plain airfoil increased up to a Reynolds number of about 1.0×10^6 and then remained nearly constant up to a Reynolds number of about 3.0×10^6, the limit of the tests. For flap deflections above 15°, the slope of the section lift curve decreased with increase in flap deflection.

The section drag coefficient with flap deflected remained almost constant with Reynolds number, although the section drag coefficient for the plain airfoil decreased up to a Reynolds number of about 0.8×10^6 and then remained nearly constant to a Reynolds number of about 3.0×10^6.

The pitching-moment-coefficient slope with flap deflected was erratic, but the pitching-moment-coefficient slope for the plain airfoil became slightly more negative with increasing Reynolds number.

INTRODUCTION

Scale effect on low-drag airfoils has regularly been determined at Reynolds numbers above 3.0×10^6 in the NACA two-dimensional low-turbulence pressure tunnel (designated TDT). Tests were recently made in the TDT, in the NACA two-dimensional low-turbulence tunnel, and in the LMAL 7- by 10-foot tunnel to determine scale and turbulence effects on the lift and drag characteristics of a typical low-drag airfoil section over a wide range of Reynolds number (reference 1).

The object of the present investigation was to find the effect of Reynolds number on the aerodynamic characteristics of a typical low-drag flapped airfoil section tested under conditions of relatively high stream turbulence. The NACA 65_3-418, a = 1.0 airfoil section equipped with a split flap having a chord 20 percent of the airfoil chord (0.20c) was tested in the LMAL 7- by 10-foot tunnel over a range of Reynolds number from 0.19 to 2.99×10^6.

MODELS AND TESTS

Models

Two models of 7-foot span with chords of 1 foot and 4 feet were tested. Both models were built of laminated wood with suitable steel reinforcements and were shaped to the NACA 65_3-418 profile. Ordinates for this section were derived by the methods of reference 2 and are given in table I. Both models were carefully finished and were polished just before testing.

A 0.20c split flap was tested on each model. The flaps were made of sheet steel and were formed to the airfoil contour.

The airfoil section with the flap is shown in figure 1.

Tests

The models were mounted vertically in the tunnel so that the test section was spanned completely except for a small clearance at each end. The models were rigidly attached to the balance frame by torque tubes extending through the tunnel walls. The angle of attack was set by rotating the torque tubes by means of a calibrated electric drive. This installation is thought to approximate closely two-dimensional flow, thus making it possible to determine the section characteristics of the models being tested. This setup is described in reference 3.

Each model was tested at dynamic pressures of 1.02, 4.09, 9.21, and 16.37 pounds per square foot, which correspond to tunnel airspeeds of approximately 20, 40, 60, and 80 miles per hour, respectively. These airspeeds correspond to test Reynolds numbers of 0.19, 0.37, 0.56, and 0.75×10^6, respectively, for the model of 1-foot chord and 0.75, 1.50, 2.24, and 2.99×10^6, respectively, for the model of 4-foot chord. The turbulence factor of the LMAL 7- by 10-foot tunnel is 1.6. Although the data are presented for various test Reynolds numbers, the corresponding effective Reynolds numbers can be obtained by multiplying the test Reynolds numbers by the turbulence factor. The highest Mach number reached was 0.10, so that no effect of Mach number on maximum lift coefficient is thought to be present (reference 4).

At each tunnel airspeed, each model was tested both as a plain airfoil and with the flap attached and deflected 15°, 30°, and 60°. The flap deflections were set by means of templets and were checked after each test. The flap was sufficiently braced so that no perceptible deflection occurred under load.

Balance readings were used to measure lift, drag, and pitching moment, except for the drag of the plain airfoil. Because of the insensitivity of the tunnel balance system, particularly at low speeds, the drag of the plain airfoil was obtained from wake-survey tests.

The angle of attack ranged from a negative angle through the stall for each test. In most cases, readings were taken at 2° intervals, with 1° increments near the stall.

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PRESENTATION OF RESULTS

Coefficients and Symbols

The test results are presented in the form of standard nondimensional section coefficients. The coefficients and symbols used are defined as follows:

c_l section lift coefficient (l/qc)

c_{d_o} section profile-drag coefficient (d_o/qc)

$c_{m_{c/4}}$ section pitching-moment coefficient about quarter-chord point (m/qc^2)

$c_{l_{max}}$ maximum section lift coefficient

where

l section lift

d_o section profile drag

m section pitching moment about quarter-chord point

q free-stream dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

c airfoil chord, feet

V airspeed, feet per second

ρ mass density of air, slugs per cubic foot

and

R Reynolds number ($\rho Vc/\mu$)

M Mach number (V/a)

a speed of sound (1129 fps)

μ viscosity of air, pound-seconds per square foot

α_o angle of attack for infinite aspect ratio

δ_f flap deflection, measured from flap-retracted position

$dc_l/d\alpha_o$ slope of lift curve for infinite aspect ratio

Precision

Accuracy of test results.- The experimental errors in the results presented herein are believed to be within the limits indicated in the following table:

R	Chord (ft)	Limit of accuracy		
		$c_{l_{max}}$	$c_{m_{c/4}}$	c_{d_o} at $c_l = 0.4$
0.19×10^6	1	±0.10	±0.05	±0.015
.37	1	±.08	±.03	±.010
.56	1	±.06	±.02	±.007
.75	1	±.04	±.015	±.003
.75	4	±.06	±.015	±.008
1.50	4	±.05	±.012	±.004
2.24	4	±.04	±.009	±.001
2.99	4	±.03	±.006	±.0006

The average errors are much smaller. With flap deflected, errors may be as much as three times the values given. The angle of attack and flap deflection were held within the following limits of accuracy:

α_o, degrees . . . . ±0.2
δ_f, degrees . . . . ±0.2

Wind-tunnel corrections.- The lift coefficients are corrected for tunnel interference effects (reference 3). The drag coefficients for the plain airfoil, which were obtained from wake-survey tests, were corrected for blocking as in reference 1. No corrections to the drag and pitching-moment coefficients have been determined for two-dimensional force tests in the LMAL 7- by 10-foot tunnel.

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DISCUSSION

The curves of section angle of attack, section profile-drag coefficient, and section pitching-moment coefficient against section lift coefficient, for the various Reynolds numbers investigated, are presented in figure 2.

Lift.- The angle of attack at the maximum lift coefficient seems to increase progressively with Reynolds number. There is no scale effect on the angle of attack for zero lift, although there is an unexplained difference between the angles for zero lift of the models of 1-foot and 4-foot chord. As shown by the curves of maximum section lift coefficient against Reynolds number (fig. 3), the scale effect on $c_{l_{max}}$ is of the usual form; that is, $c_{l_{max}}$ increases with increasing R. Moreover, deflecting the split flap adds an almost constant increment of $c_{l_{max}}$ through the Reynolds number range. This effect is usual for a split flap (reference 5). The scale effect on the slope of the lift curve within the low-drag range is given in figure 4. The slope of the lift curve for the plain airfoil increases up to a Reynolds number of about 1.0×10^6 and then remains almost constant up to a Reynolds number of about 3.0×10^6, the limit of the tests. With flap deflected, the slope is erratic but approximately constant with Reynolds number. For flap deflections above 15°, the slope of the lift curve decreases with increase in flap deflection.

Drag.- The effect of Reynolds number on the section profile-drag coefficient is shown in figure 5. The drag coefficients for the plain airfoil were obtained from wake-survey tests; the drag coefficients for the airfoil with flap deflected were obtained from force tests. All drags were taken at the angle of attack corresponding to the design lift coefficient (0.4) of the plain airfoil; this value corresponds to an angle of attack of about 1°.

For the plain airfoil, the drag decreases sharply with increasing Reynolds number below a Reynolds number of about 0.8×10^6. Above this Reynolds number, the drag remains nearly constant.

For the airfoil with flap deflected, the results show no consistent variation of section profile-drag coefficient with Reynolds number. In fact, it may be concluded from these results that the section profile-drag coefficient with flap deflected is, to a first approximation, independent of Reynolds number.

Pitching moment.- The somewhat irregular curves of section pitching-moment coefficient at the lowest Reynolds numbers appear to be caused by the inaccuracy of the tunnel balance system at the low speeds. This inaccuracy is also shown by the large difference between the original and check tests at $R = 0.19 \times 10^6$ (fig. 2(a)).

Accuracy at Reynolds numbers higher than 0.19×10^6 is much better, as shown by the table in the section entitled "Precision." The slope of the pitching-moment-coefficient curve of the plain airfoil becomes slightly more negative with increase in Reynolds number (fig. 6). The pitching-moment-coefficient slope for the airfoil with flap deflected varied with lift coefficient in such a way that presentation of the slopes was not practicable.

CONCLUSIONS

Scale-effect tests of the NACA 65_3-418, a = 1.0 airfoil section with a split flap having a chord 20 percent of the airfoil chord have been made in the LMAL 7- by 10-foot tunnel. The Reynolds number ranged from 0.19 to 2.99×10^6; the Mach number attained was never greater than 0.10. From these tests, the following conclusions have been drawn:

1. The maximum lift coefficient increased with Reynolds number. Deflecting the flap added an increment of maximum lift coefficient that seemed to be almost constant at all Reynolds numbers.

2. The slope of the section lift curve with flap deflected showed no consistent variation with Reynolds number, although the slope of the section lift curve for the plain airfoil increased up to a Reynolds number of about 1.0×10^6 and then remained nearly constant up to a Reynolds number of about 3.0×10^6, the limit of the tests.

3. For flap deflections above 15°, the slope of the section lift curve decreased with increase in flap deflection.

4. The section profile-drag coefficient with flap deflected remained almost constant with Reynolds number, although the section profile-drag coefficient for the plain airfoil decreased up to a Reynolds number of about 0.8×10^6 and then remained nearly constant to a Reynolds number of about 3.0×10^6.

5. The slope of the pitching-moment-coefficient curve of the plain airfoil became slightly more negative with increase in Reynolds number. The pitching-moment-coefficient slope for the airfoil with flap deflected varied with lift coefficient in such a way that presentation of the slopes was not practicable.

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3. Wenzinger, Carl J., and Harris, Thomas A.: Wind-Tunnel Investigation of an N.A.C.A. 23012 Airfoil with Various Arrangements of Slotted Flaps. NACA Rep. No. 664, 1939.

4. Stack, John, Fedziuk, Henry A., and Cleary, Harold E.: Preliminary Investigation of the Effect of Compressibility on the Maximum Lift Coefficient. NACA ACR, Feb. 1943.

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TABLE I

ORDINATES OF NACA 65_3-418, a = 1.0 AIRFOIL SECTION

[Stations and ordinates in percent airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.28	1.42	.72	-1.22
.50	1.73	1.00	-1.45
.97	2.21	1.53	-1.78
2.18	3.10	2.82	-2.36
4.64	4.48	5.36	-3.22
7.12	5.57	7.88	-3.87
9.62	6.48	10.38	-4.41
14.64	7.94	15.36	-5.25
19.67	9.06	20.33	-5.88
24.72	9.91	25.28	-6.33
29.77	10.54	30.23	-6.65
34.83	10.94	35.18	-6.82
39.88	11.14	40.12	-6.86
44.94	11.09	45.06	-6.71
50	10.77	50	-6.36
55.05	10.20	54.95	-5.82
60.09	9.41	59.91	-5.12
65.13	8.45	64.87	-4.33
70.15	7.37	69.85	-3.48
75.15	6.18	74.85	-2.60
80.15	4.93	79.85	-1.74
85.13	3.64	84.87	-.95
90.09	2.35	89.91	-.28
95.05	1.12	94.95	.14
100	0	100	0
L.E. radius: 1.96 Slope of radius through end of chord: 0.168			

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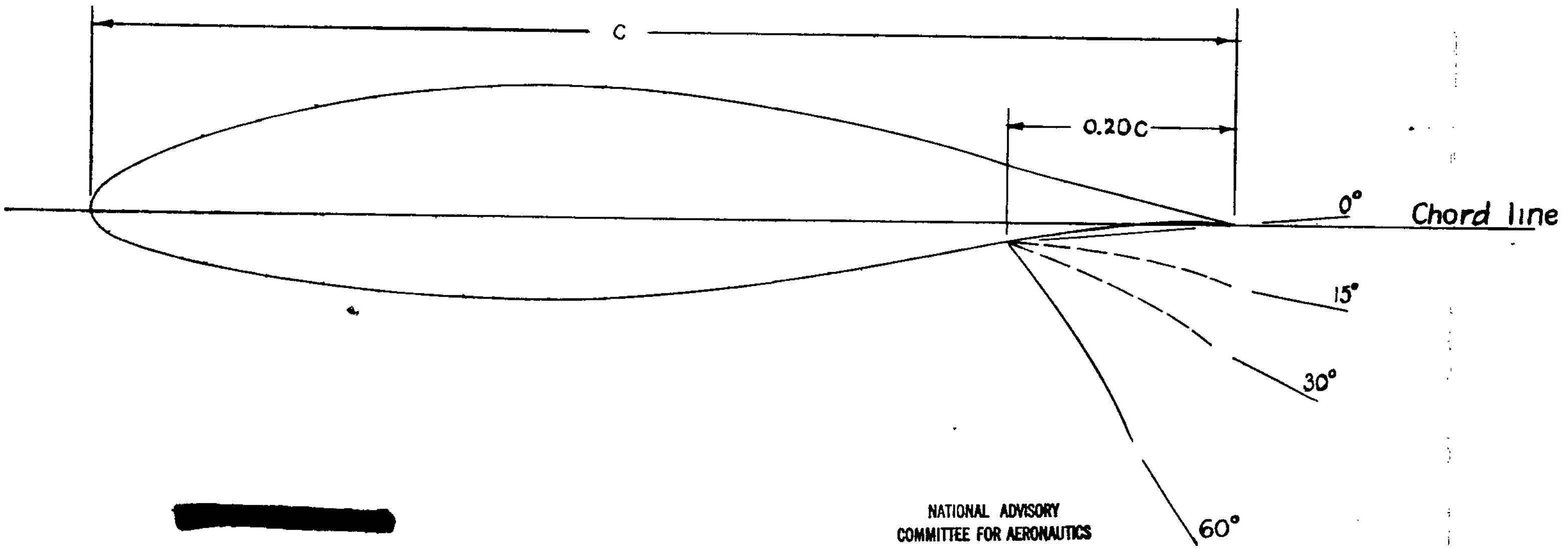

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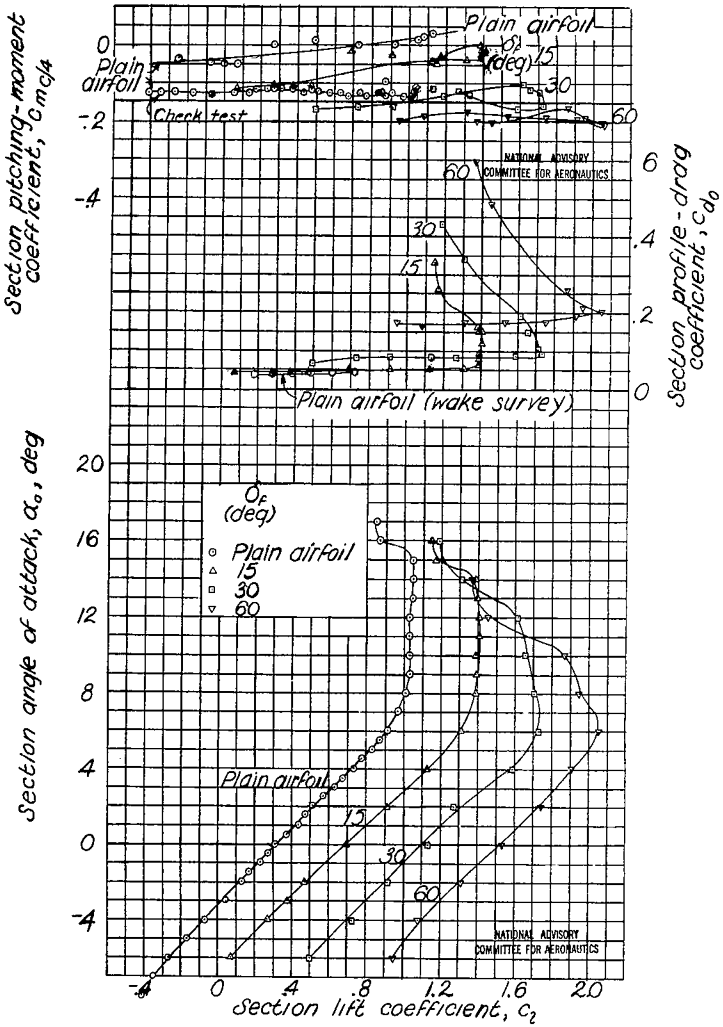
Figure 1.- NACA 65_3-418, a=1.0 airfoil section with 0.20c split flap.



(a) One-foot-chord model. $R = 0.19 \times 10^6$; $M = 0.03$.

Figure 2.- Aerodynamic section characteristics of NACA 65_3-418 airfoil with a 0.20c split flap.

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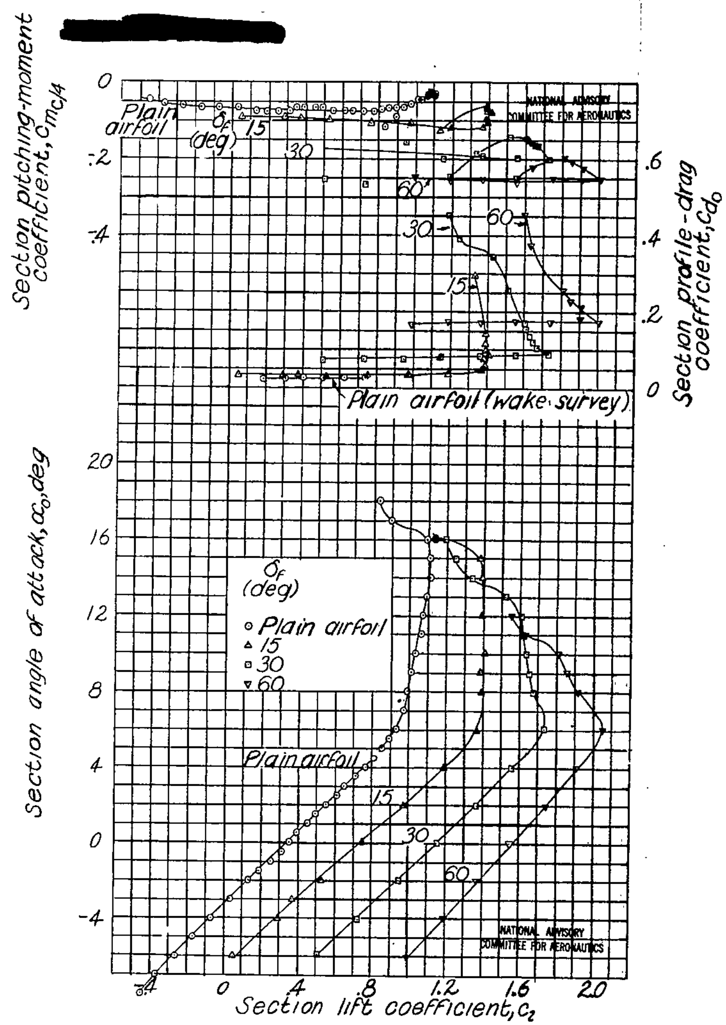
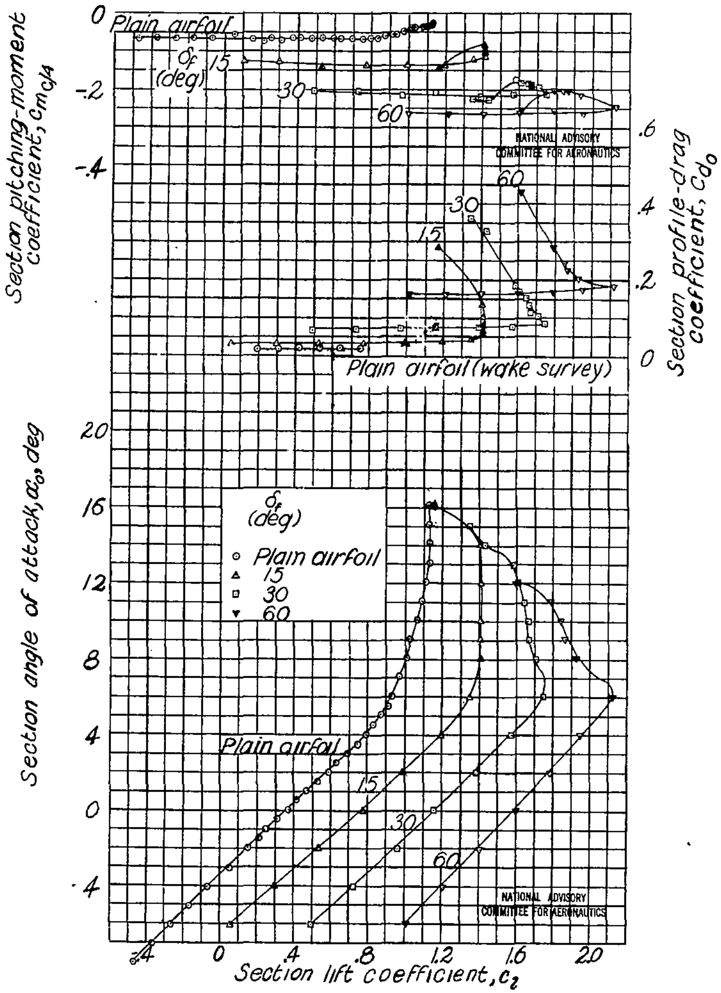


(b) One-foot-chord model. $R = 0.37 \times 10^6$; $M = 0.05$.

Figure 2.- Continued.

[redacted]

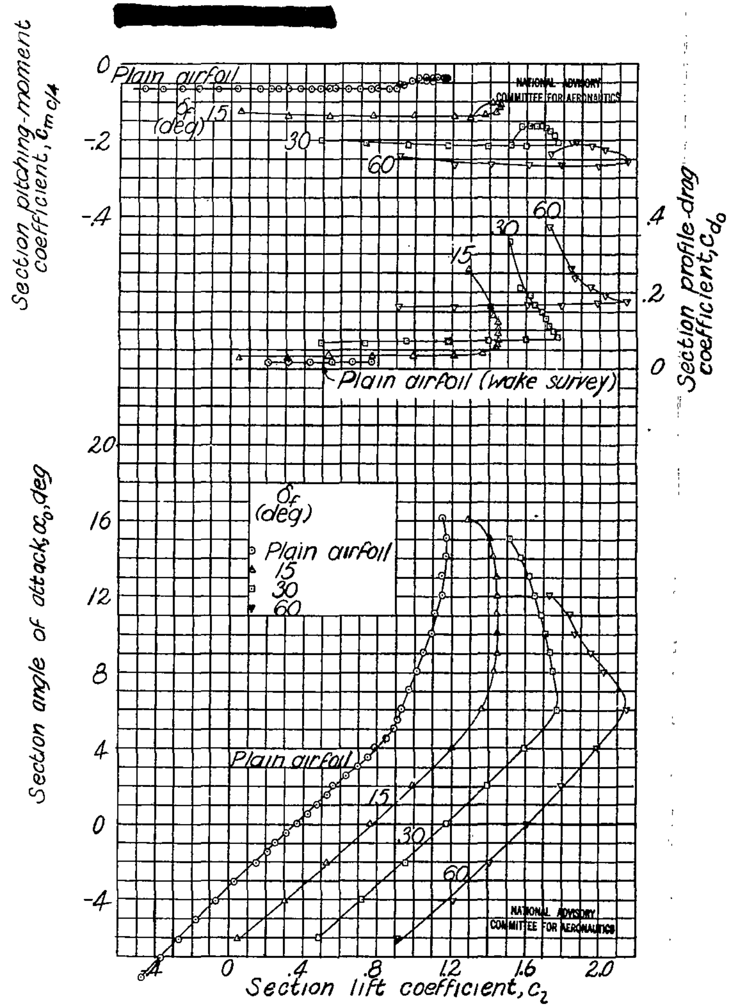


(c) One-foot-chord model. $R = 0.56 \times 10^6$; $M = 0.08$.

Figure 2.- Continued.

[redacted]

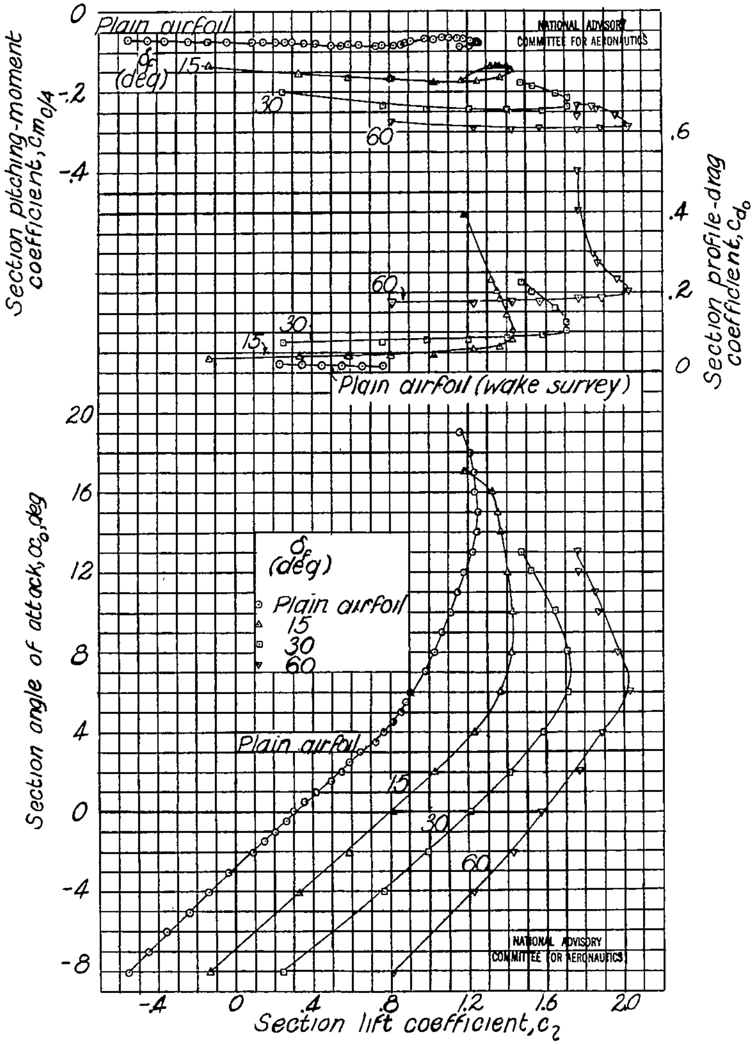
[redacted]



(d) One-foot-chord model. $R = 0.75 \times 10^6$; $M = 0.10$.

Figure 2. - Continued.

[redacted]



(e) Four-foot-chord model. $R = 0.75 \times 10^6$; $M = 0.03$.

Figure 2.- Continued.

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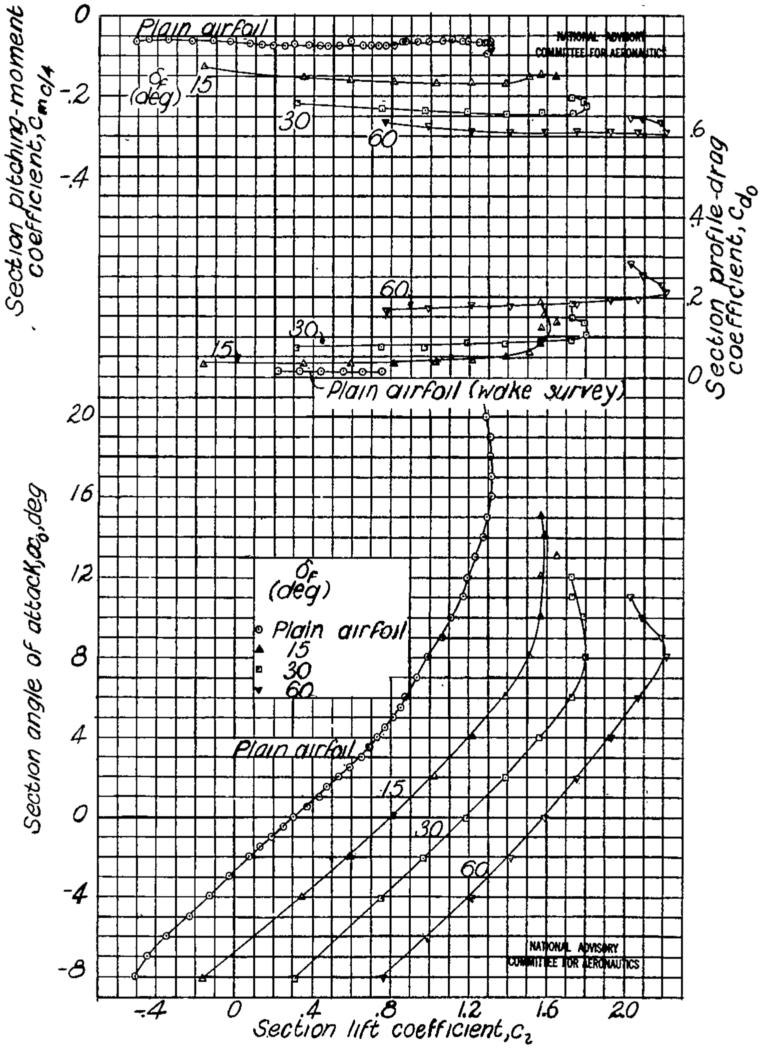
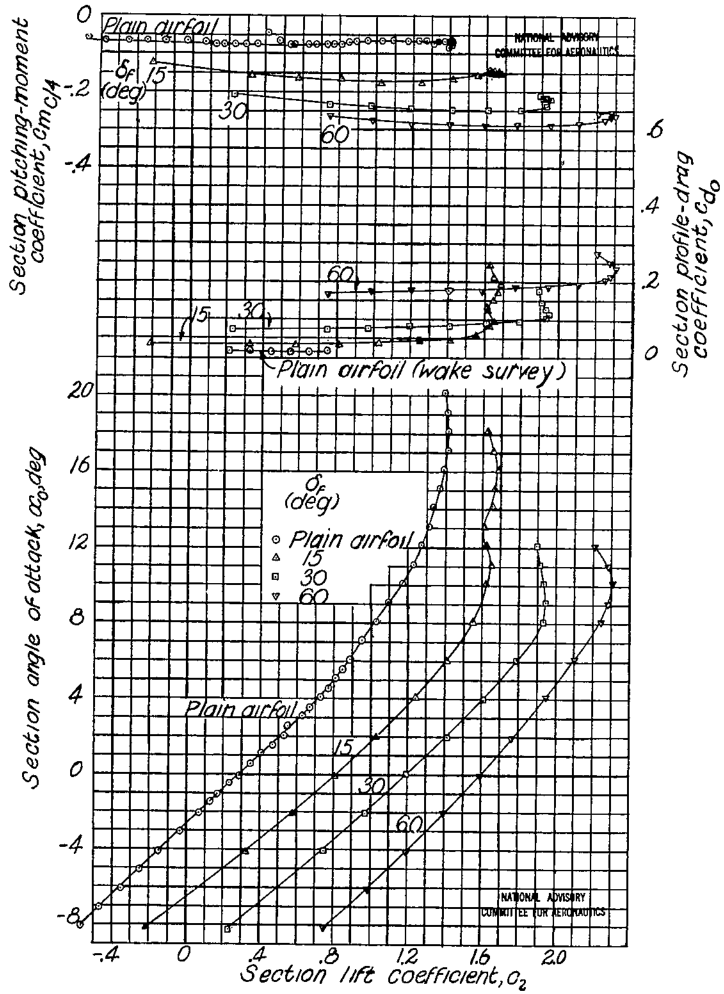


(f) Four-foot-chord model. $R = 1.50 \times 10^6$; $M = 0.05$.

Figure 2.- Continued.



(g) Four-foot-chord model. $R = 2.24 \times 10^6$; $M = 0.08$.

Figure 2.- Continued. [redacted]

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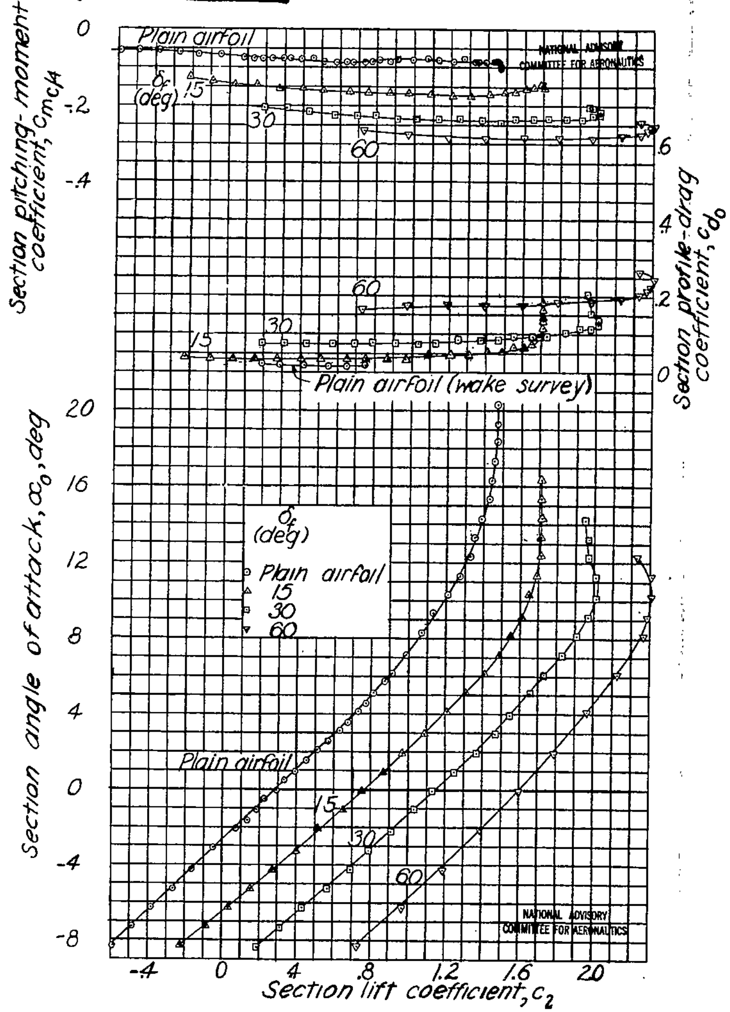

(h) Four-foot-chord model. $R = 2.99 \times 10^6$; $M = 0.10$.

Figure 2.- Concluded.

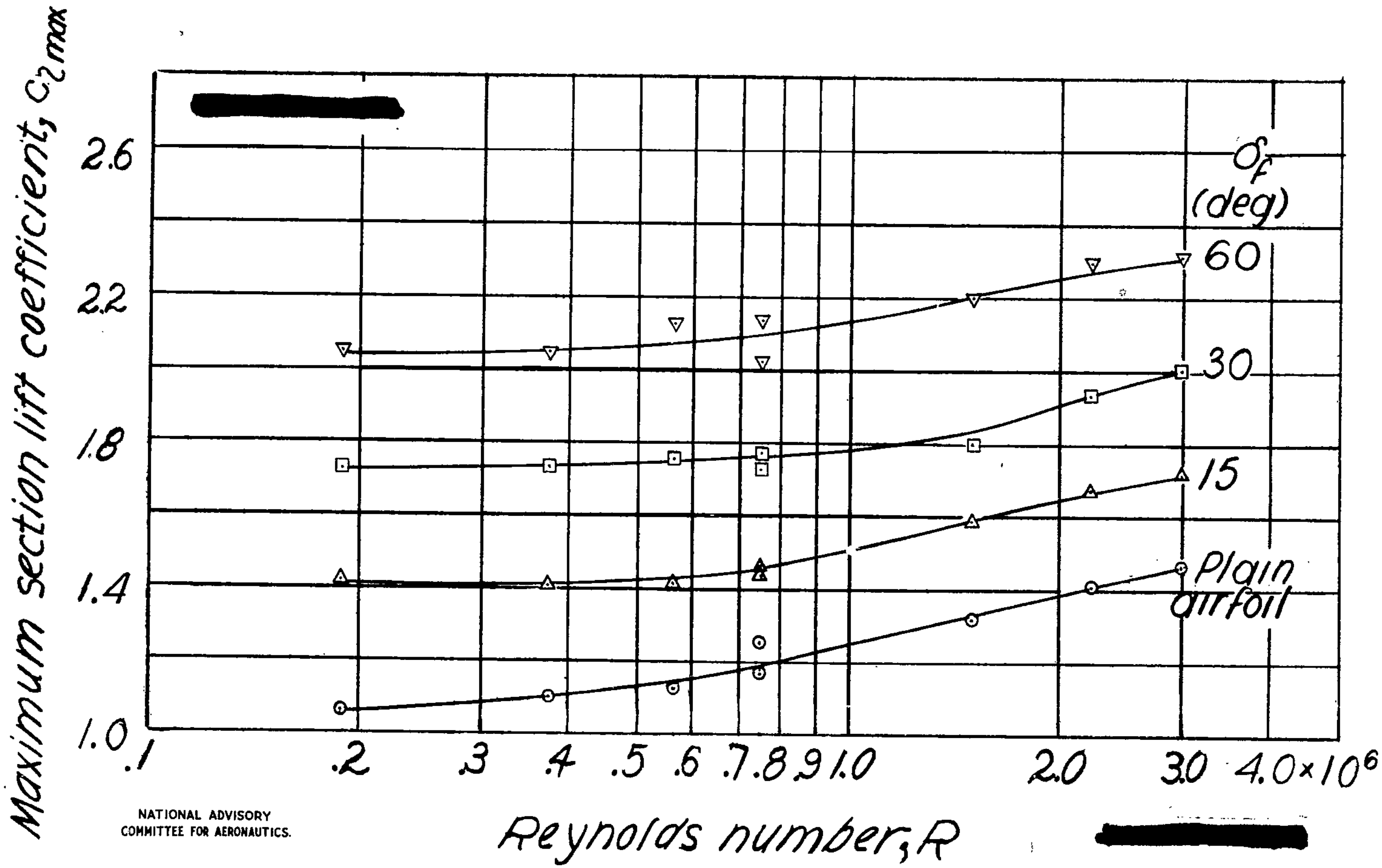

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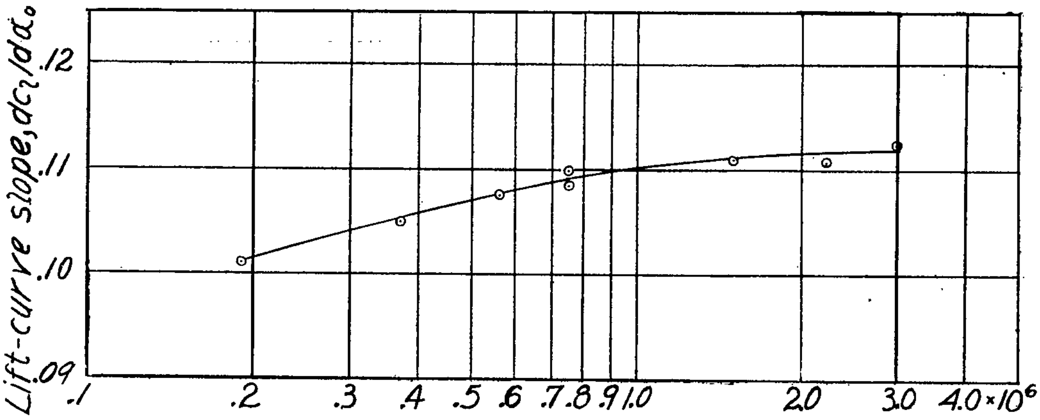
Figure 3.- Scale effect on maximum lift coefficient of NACA 65_3-418 airfoil section with a 0.20c split flap.



(a) Plain airfoil.

Figure 4.- Scale effect on lift-curve slope of the NACA 65_3-418 airfoil section.

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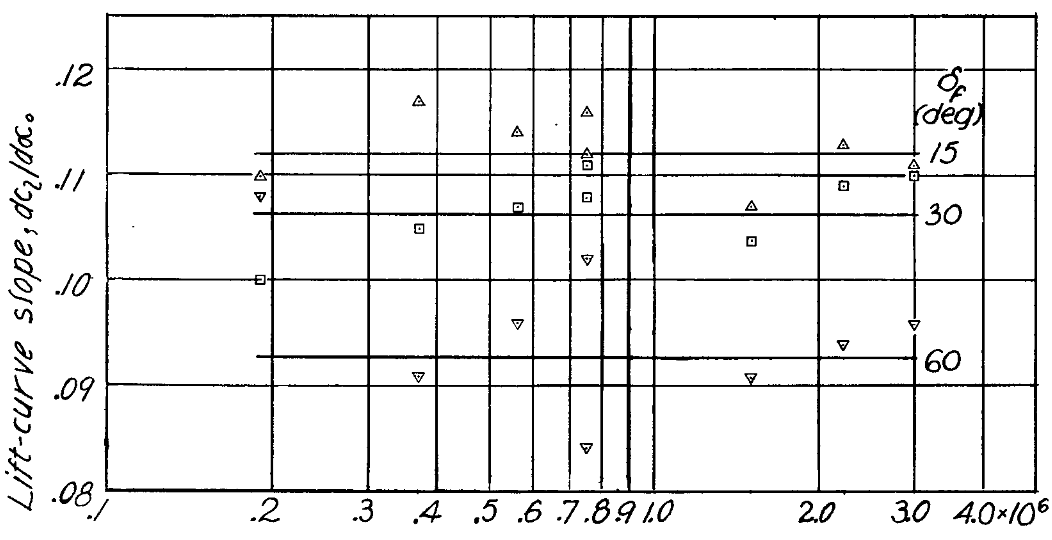
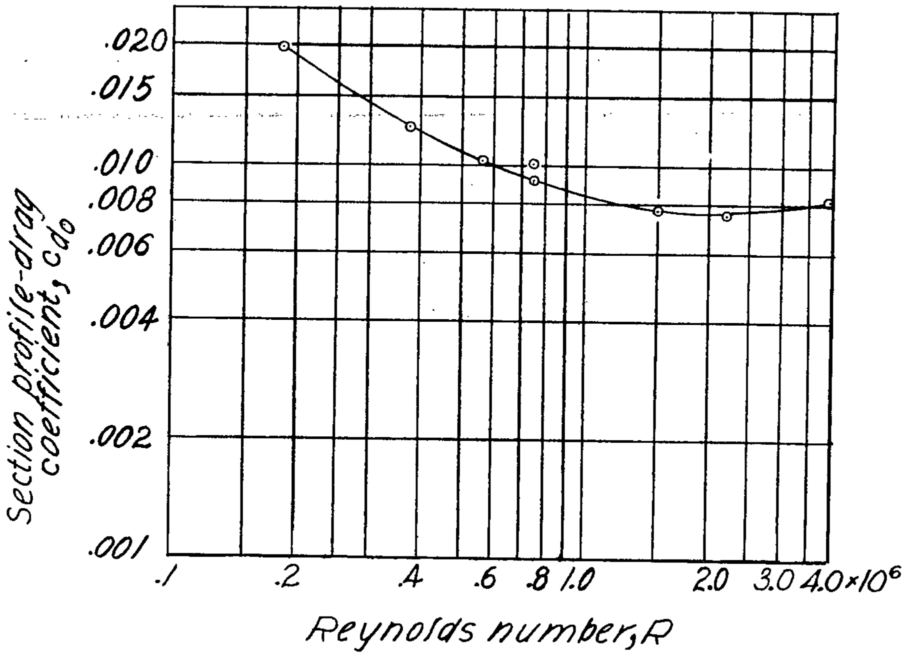


(b) Flap deflected; $\alpha_0 \approx 0°$. [redacted]

Figure 4.- Concluded.



(a) Plain airfoil (wake-survey tests); $\alpha_0 \approx 1°$.
Figure 5.- Scale effect on drag coefficient at the design lift coefficient of the NACA 65_3-418 airfoil section.

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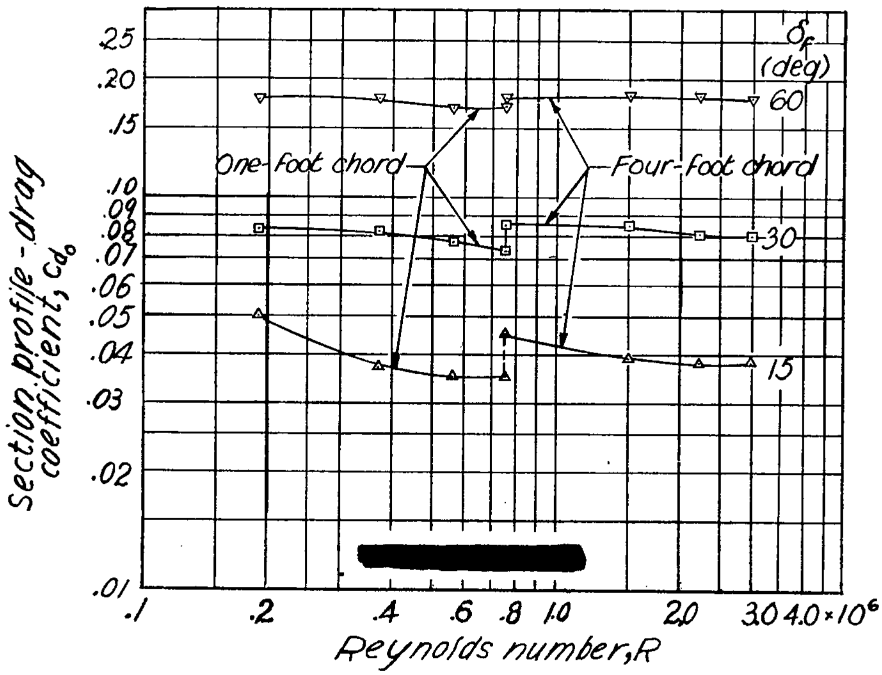

(b) Flap deflected (force tests); $\alpha_0 \approx 1°$.
Figure 5.- Concluded.

[redacted]

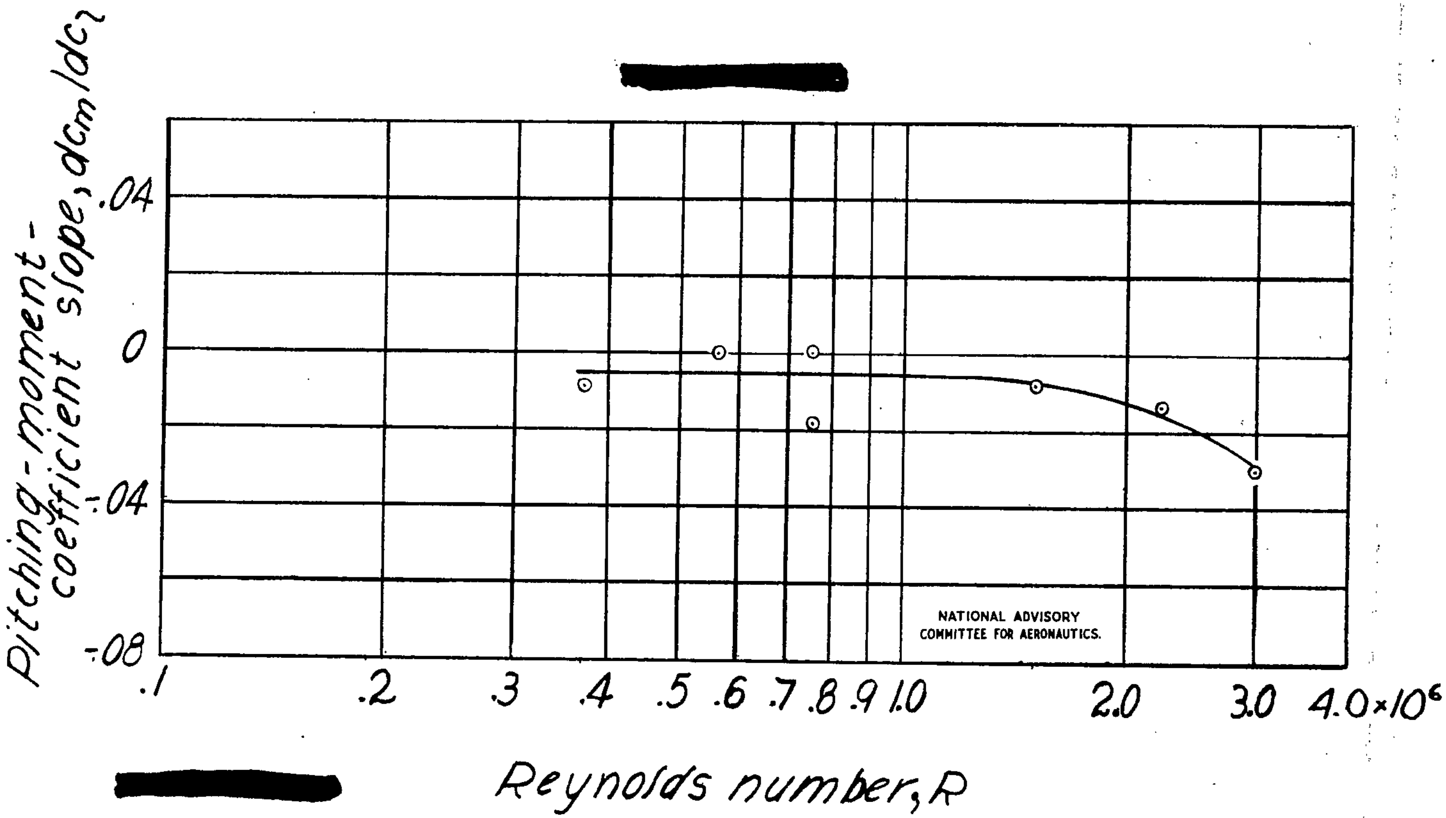

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Figure 6.- Scale effect on pitching-moment-coefficient slope of the NACA 65_3-418 airfoil section. Plain airfoil.